USAARL Report No. 89-18

Evaluation of Two Objective Measures of Effective Auditory Stimulus Level

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August 1989

United States Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
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1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 89-18	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Sensory Research Division U.S. Army Aeromedical Rsch Lab 6b. OFFICE SYMBOL (If applicable) SGRD-UAS-AS	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Development Command
6c. ADDRESS (City, State, and ZIP Code) P. O. Box 577 Fort Rucker, AL 36362-5292	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21701-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: - PROJECT NO.: 3E162787A878 TASK NO.: WORK UNIT ACCESSION NO.: 135

11. TITLE (Include Security Classification)

Evaluation of two objective measures of effective auditory stimulus level

12. PERSONAL AUTHOR(S)
Ted L. Langford, Ben T. Mozo, and James H. Patterson, Jr.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM _____ TO _____	1989 August	19

16. SUPPLEMENTARY NOTATION

Key words draft

17 COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Auditory brainstem response; auditory mid-latency response; hearing protectors; effective stimulus level (KT)
06	04		
24	07		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The brainstem auditory evoked response and the 40-Hz component of the auditory mid-latency response were measured in human subjects as a function of stimulus frequency and level to determine whether one of the two could be used to provide a reliable estimation of the amount of attenuation provided by hearing protective devices in situations in which the time available for measurement is restricted. Under the conditions of the present experiment, the variability of the data for both types of measure was too great to permit a reliable estimation of effective stimulus level. Cont'd pg 2

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Scientific Information Center	22b. TELEPHONE (Include Area Code) (205) 255-6907 22c. OFFICE SYMBOL SGRD-UAX-SI

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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Introduction

Potentially harmful noise levels in many military environments require the use of hearing-protective devices by personnel operating in those environments. A rapid, reliable, and valid method for the field measurement of the amount of attenuation afforded by the various hearing protectors is needed to ensure that the devices are being properly used and are effective in reducing noise exposure. At present, a method for objectively measuring the attenuation of hearing protectors in a field environment is not available.

The purpose of the present study was to determine if evoked auditory potentials could provide objective measures which could be used as dependent variables in a more extensive study of the attenuation characteristics of hearing-protection devices. An additional purpose of the work was to provide baseline, laboratory data as a comparison for the field work of the attenuation study.

Noninvasive, electrophysiological recording techniques have been used to objectively measure the biologically effective levels of auditory stimuli in both laboratory and clinical settings. Such measures are objective in that they do not require a judgment on the part of the subject. Indeed, no overt response or active participation at all is required of the subject in order for a valid measurement to be made.

At present, the most commonly used of these measures is the auditory brainstem response (ABR). The ABR consists of a series of short-latency electrical potentials evoked by brief stimuli and recorded by surface electrodes placed at various locations on the head. The potentials are averaged over a number of stimulus presentations to isolate activity temporally locked to the stimulus from the random background activity. Wave V of the ABR can be reliably identified by trained observers over a wide range of measurement conditions and its latency in persons with normal hearing varies in a predictable manner with the level of the stimulus (Moore, 1983). Although human judgment and error have always been factors in measuring the latency of Wave V, several automated, statistical procedures are under development to objectively detect this wave (cf., Elberling and Don, 1987; Salvi et al., 1987).

A recently developed measure, the 40-Hz evoked response, is not yet in general use as a standard in auditory work. This response is derived from three waves of the mid-latency responses (MLR) which follow the ABR. These waves have natural latencies which are multiples of the period of 40-Hz. At a stimulus

repetition rate of 40 Hz they are enhanced, making them easily detectable in the averaged waveform (Galambos et al., 1981; Lenarz et al., 1986; Sammeth and Barry, 1985). This enhanced potential can be recorded from the same electrode placements as used for the ABR. Although there are a few reports regarding latency changes produced by changes in stimulus level, at present the dependent variable of choice is the amplitude of the 40-Hz MLR.

Both the ABR and the MLR have advantages and disadvantages as measures of the effectiveness of auditory stimulation. The ABR has been used extensively and the variation in the latency of its Wave V as a function of effective stimulus level is well known. On the other hand, the stimuli used in most cases are broad-band clicks, so that frequency-specific information is not produced. Another disadvantage is that different latency norms must be used for male and female subjects (Schwartz and Berry, 1985). The 40-Hz evoked MLR is reported to be a robust, frequency-specific response, which can be obtained with fewer stimulus presentations than the ABR, but it suffers from considerable variability depending on the attentional state of the subject. No data have been reported concerning possible gender differences for this measure.

Neither the ABR nor the MLR has been standardized well enough to be used in laboratory or clinical settings without considerable interpretation according to local ground rules. The stimuli which are described in most published reports have unknown frequency content and poorly specified levels. In addition, a variety of stimulus durations and repetition rates, both of which affect the ABR response (Moore, 1983), are used by different investigators. The filters used in recording are often chosen to eliminate various types of noise contamination with little regard to the resulting phase distortion of the evoked waveforms. Severe filtering can affect amplitudes, latencies and even the polarities of the waves of interest (Scherg, 1982; Janssen et al., 1986). The many electrode placements which are used also contribute to the difficulty of interpreting data from different sources.

For the above reasons, it is not possible to use evoked-response data already existing in the literature as a norm for the field study of attenuation. The present, preliminary, study was conducted to determine a feasible configuration of stimulus variables consistent with the rapid acquisition of objective data necessary for field attenuation measurements.

Materials and Methods

Both the ABRs and the MLRs were recorded from the same subjects over a range of frequencies and levels. The stimuli used were 12-ms tone bursts produced by modulating sinusoids with an 83.3-Hz haversine. These waveforms met the requirement for a brief duration without exhibiting an excessive spread of energy to non-signal frequencies.

The stimuli for the ABR conditions were bursts of 250, 500, 1000, 2000, and 4000 Hz presented at a rate of 10 per second. With the exception of 4000 Hz, all were presented at sensation levels (SL) of 20, 35, and 50 dB. The levels for the 4000-Hz conditions were 20, 30, and 40 dB SL.

The same frequencies were used for the MLR conditions as were used for the ABR. At frequencies other than 4000 Hz, the levels were 20, 30, 35, 40, and 50 dB SL. At 4000 Hz, the levels were 20, 30, and 40 dB SL. The repetition rate was 40 per second.

The signals for both the ABRs and the MLRs were conducted to the ear from a TDH-49 headphone, sealed to a 2-ml coupler, by a length of polyethelene tubing. The tip of the tubing was passed through an opening in an E-A-R* plug, which was used to seal the tube to the ear canal of the subject. Resonances in the tubing were damped by the insertion of tufts of steel wool into each end of the tubing. The headphone-coupler-tubing combination was calibrated with an additional 2-ml coupler and 0.5-inch microphone in place of the subject's ear. The waveforms and spectra for each frequency of tone burst measured in this manner are shown in Figures 1-5. The second harmonic distortion products were at least 35 dB below the signal levels at all frequencies, with the exception of 250 Hz, where the second harmonic was 33.7 dB lower than the signal.

Ten young adults, seven males and three females, selected from the subject pool of a local community college, were used in the experiment. Each subject was screened for acceptable hearing on the basis of a pure-tone audiogram obtained for each ear. Acceptable hearing was defined as thresholds between -10 dB and 20 dB at standard audiometric frequencies (ANSI S12.6, 1984). No other selection criteria were employed. The subjects were comfortably positioned in a reclining chair inside a double-walled Tracoustics audiometric testing booth for the recording sessions. Instructions were given them to relax during the

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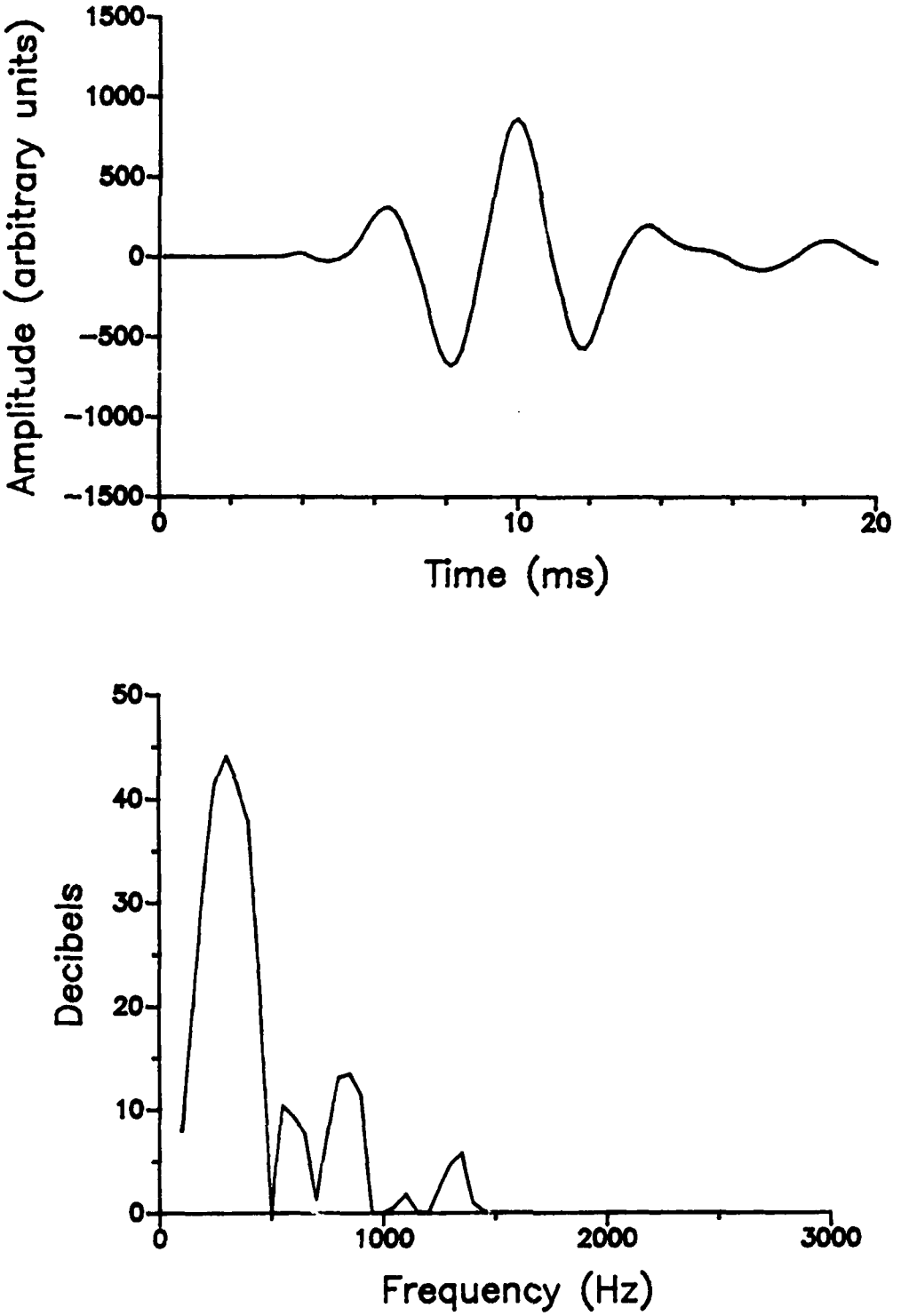

Figure 1. Waveform (upper panel) and spectrum (lower panel) for 250-Hz signal.

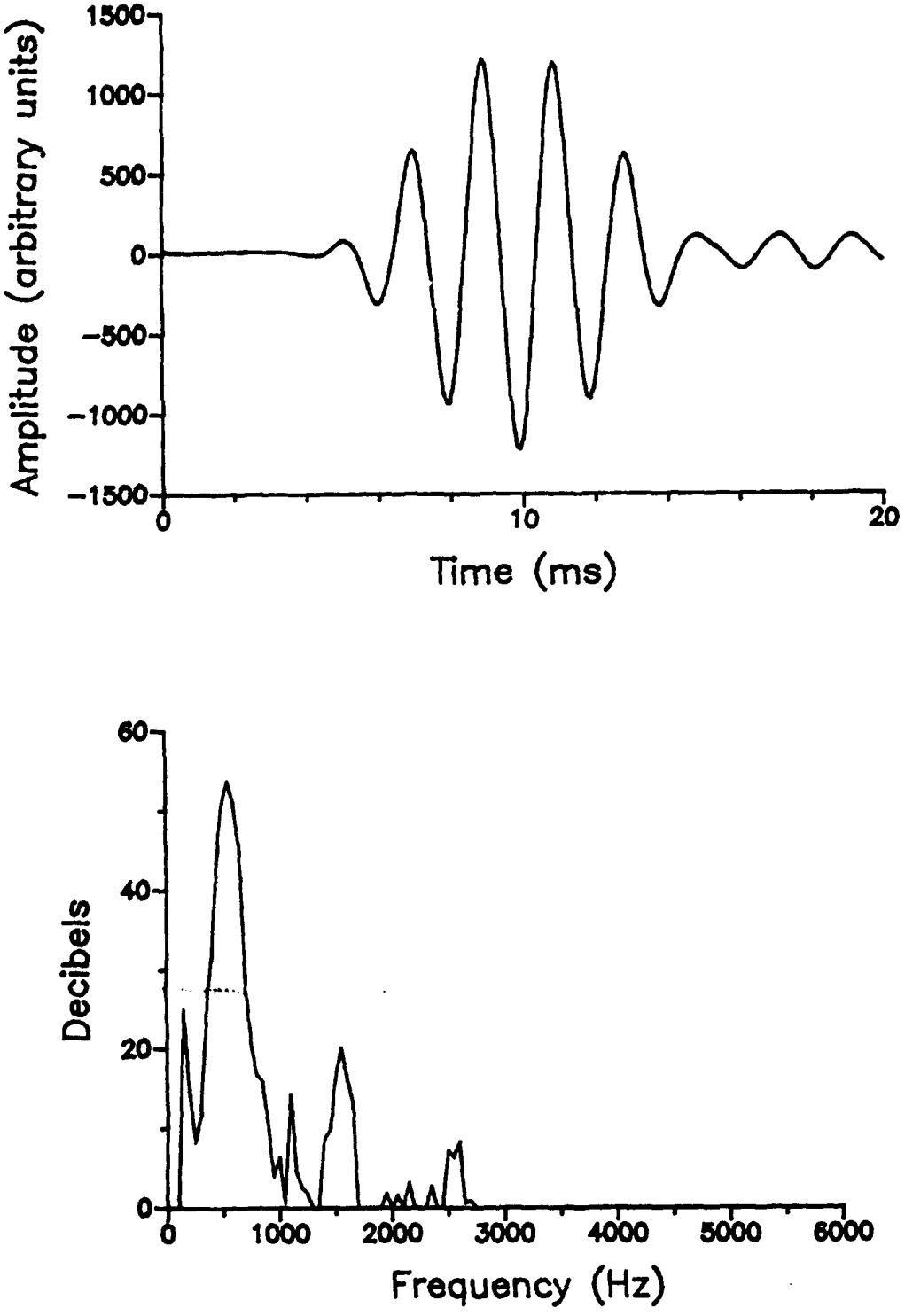

Figure 2. Waveform (upper panel) and spectrum (lower panel) for 500-Hz signal.

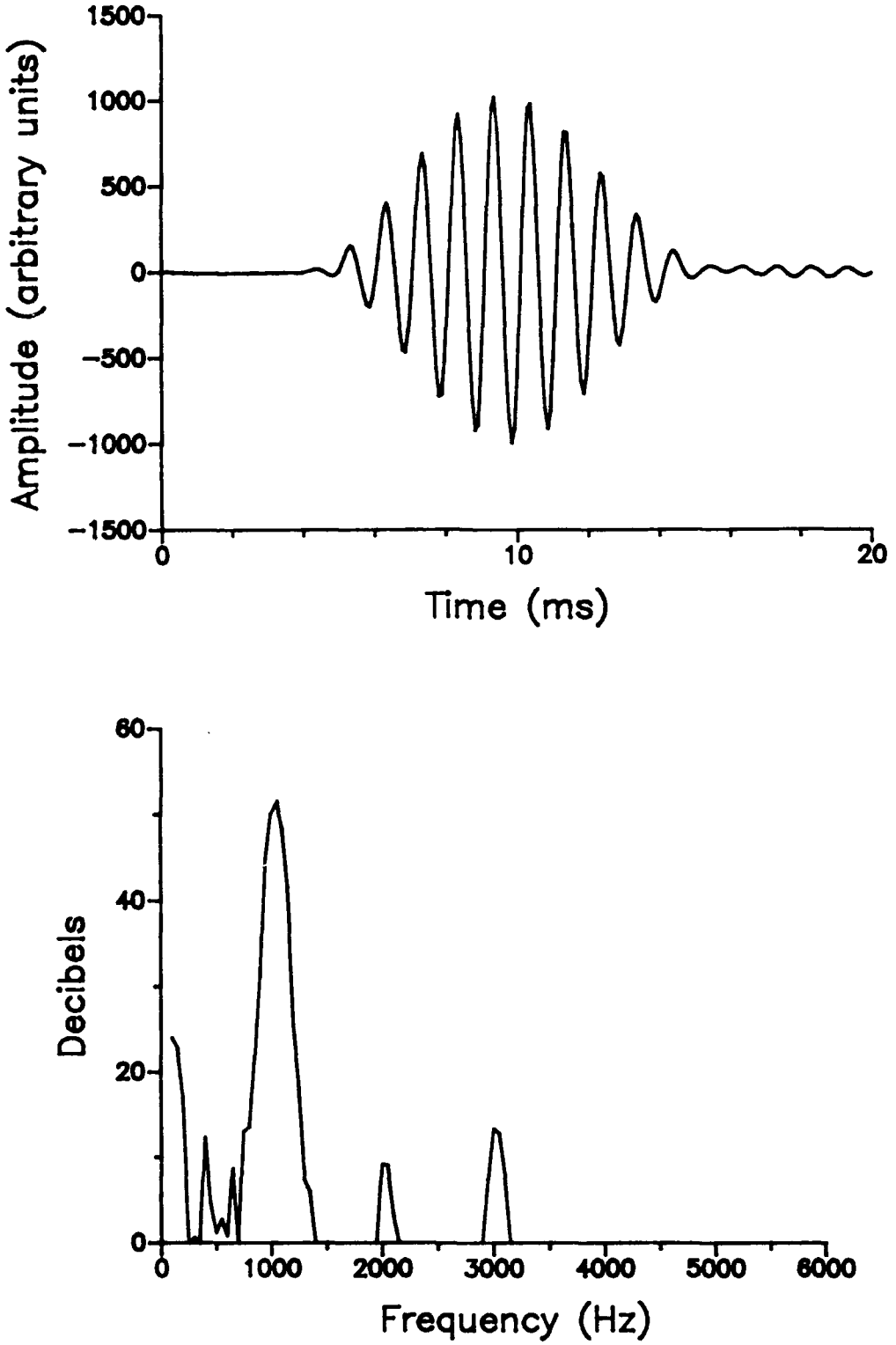

Figure 3. Waveform (upper panel) and spectrum (lower panel) for 1000-Hz signal.

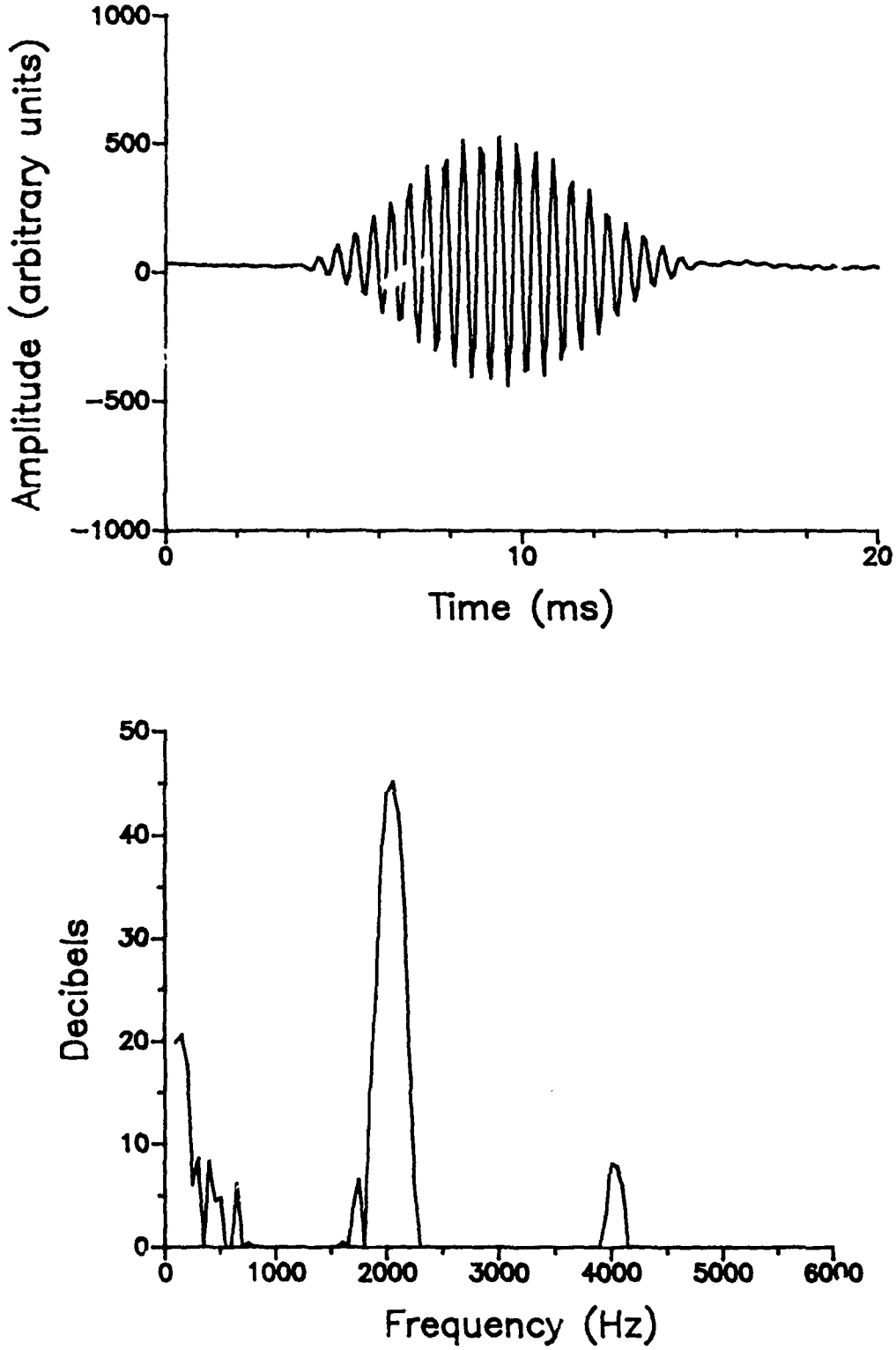

Figure 4. Waveform (upper panel) and spectrum (lower panel) for 2000-Hz signal.

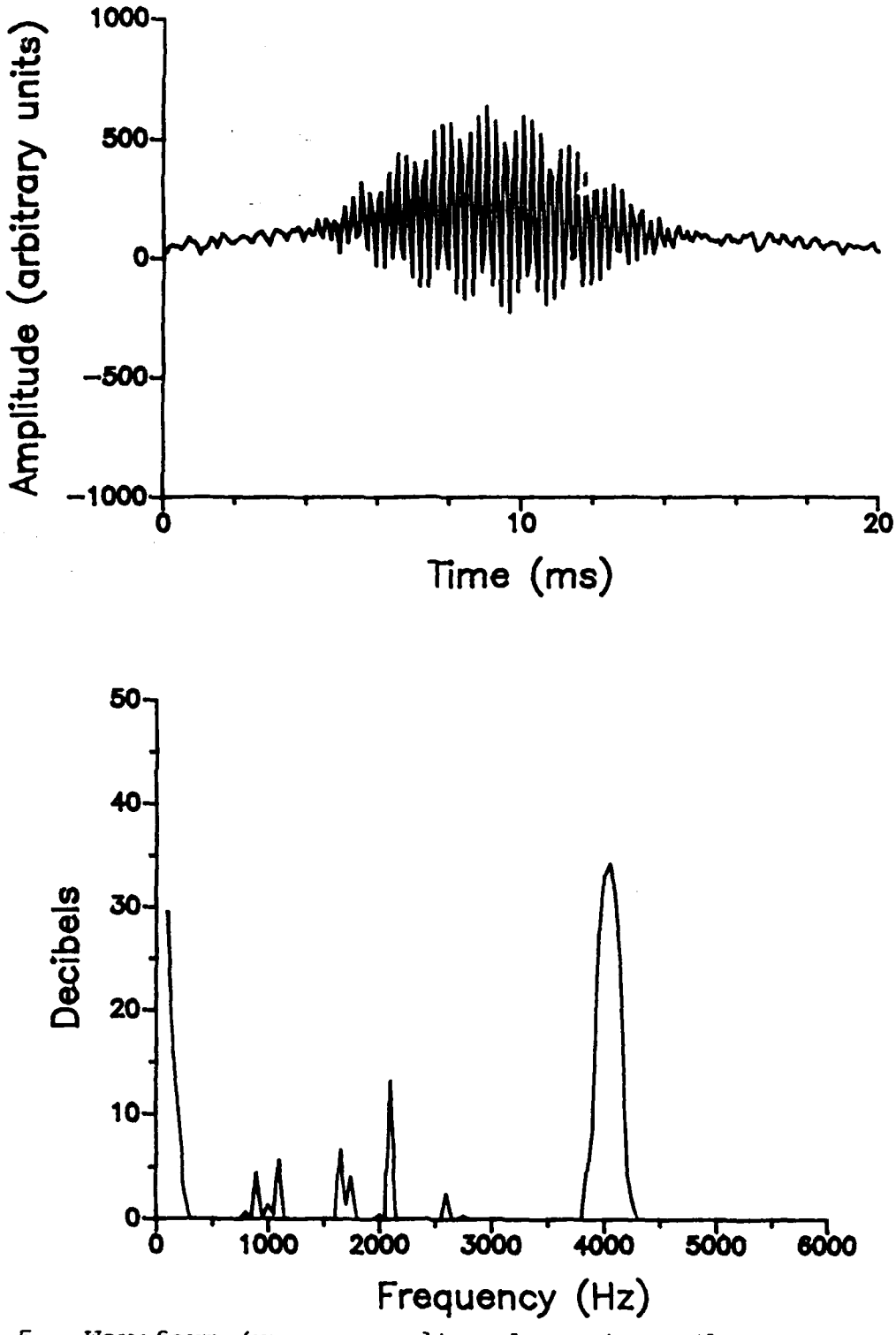

Figure 5. Waveform (upper panel) and spectrum (lower panel) for 4000-Hz signal.

recording sessions and most slept during the ABR recordings. For the MLR recordings, they were instructed to remain relaxed but alert. The experimenter made frequent checks to ensure that the subjects were awake, but no assessment of the degree of alertness was attempted.

Commercial, adhesive-backed disposable surface electrodes were used for the recordings. The same electrode array was used for both the ABR and the MLR recordings. The positive input to a differential isolation amplifier was obtained from the forehead, the negative input from the mastoid contralateral to the ear stimulated and the ground from the ipsilateral ear lobe.

The ABRs were filtered with a pass band of 5 to 2000 Hz and the MLRs with a pass band of 5 to 60 Hz. After filtering, the waveforms were digitized by a 12-bit A-to-D converter and averaged by an IBM XT-compatible computer.

Rapid data acquisition is a requirement for the field study and each ABR was based on 2000 stimulus repetitions. The results of a pilot experiment using a single subject had indicated that this number of repetitions would produce an adequate signal-to-noise ratio. The averaged waveforms were displayed on-line and stored on disk for more detailed analyses off-line.

The latency from the stimulus onset to the peak of Wave V was the dependent measure for the brainstem response. The amplitude of the 40-Hz component obtained from a fast Fourier transform of the averaged waveforms was the MLR dependent measure.

Results

The ABR results are summarized in Figure 6. The figure shows the mean latencies for all subjects at all frequencies as a function of the SL of the stimulus. Any sex differences which may have been present in the latencies were obscured by other sources of variability. The latencies, therefore, were averaged without regard to sex. The latencies shown have been corrected in this and all subsequent figures for the acoustic delay introduced by the length of tubing which conducted the stimulus to the ear. It is evident that the overall latencies for the five frequencies are ordered according to the relative positions of their travelling wave maxima along the basilar membrane. The higher frequencies, with maxima near the basal end of the membrane, are represented by short latencies and the lower frequencies, with maxima nearer the apical end, are represented by longer latencies, indicating that the responses elicited by the various stimuli were frequency-specific.

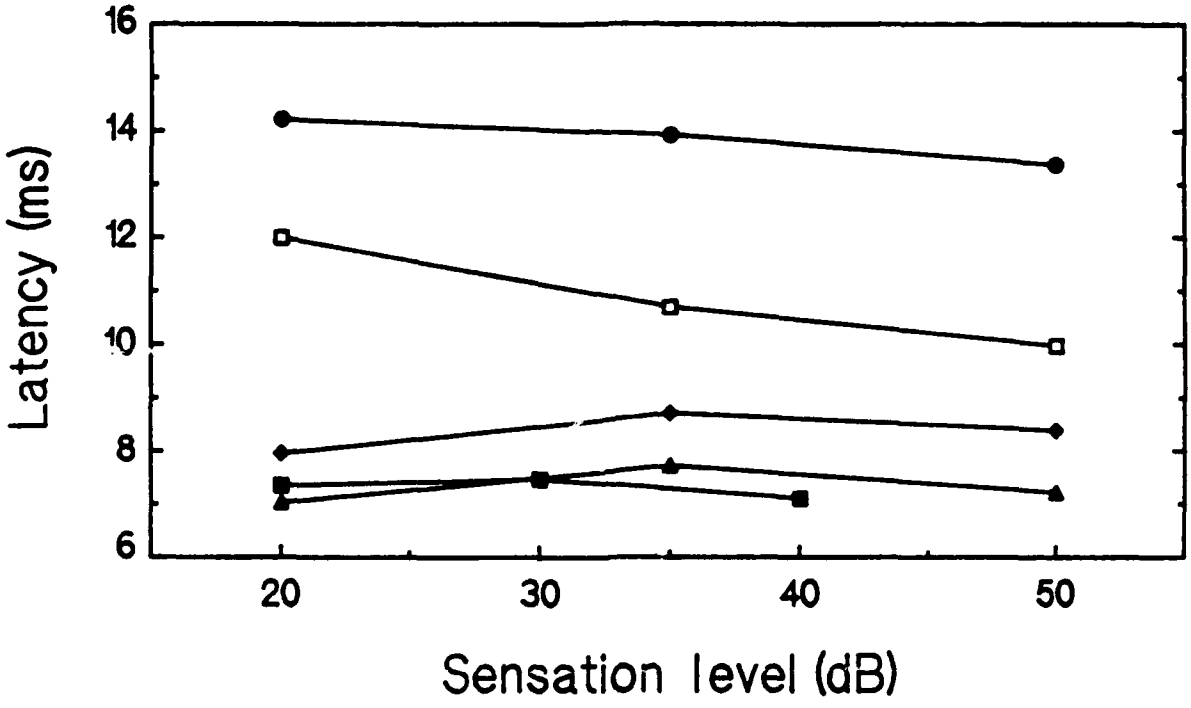

Figure 6. Mean latencies of wave V for all subjects.

Filled circles: 250 Hz Open squares: 500 Hz
Filled diamonds: 1000 Hz Filled triangles: 2000 Hz
Filled squares: 4000 Hz

The mean ABR data for the individual frequencies are presented in Table 1. With the exception of the 500-Hz data, the mean latencies show little change as a function of the stimulus intensity. In addition, at most frequencies the variability around each data point is quite high, approaching and sometimes exceeding the magnitude of the change produced by the independent variable. Several methods were attempted to reduce the variability of the data, including digital filtering of the averaged waveforms and averaging the waveforms across subjects. None of these methods produced any practical improvement.

Table 1.

ABR latencies and standard deviations.
Means for all subjects.

Sensation level (db)	Latency (ms)	Standard deviation (ms)
	0.25 kHz	
20	14.22	0.58
35	13.93	0.76
50	13.37	0.34
	0.50 kHz	
20	12.00	2.14
35	10.70	1.12
50	9.97	1.18
	1.00 kHz	
20	7.96	0.74
35	8.71	1.16
50	8.38	0.83
	2.00 kHz	
20	7.02	0.39
35	7.71	0.70
50	7.20	0.49
	4.00 kHz	
20	7.35	0.37
30	7.47	0.10
40	10.90	0.43

The mean magnitudes of the 40-Hz component of the MLRs for all subjects are shown as a function of stimulus level in Figure 7. A general trend for the magnitude of the response to increase with increasing level can be discerned, with a 30 dB increase in stimulus level producing about a 10 dB increase in the magnitude of the 40-Hz component. The variability of the response, however, is extreme as shown in the data for individual frequencies presented in Table 2. Here, as in the ABR results, the magnitude of the effect due to variation of the independent variable is obscured by the uncontrolled variation in the dependent variable.

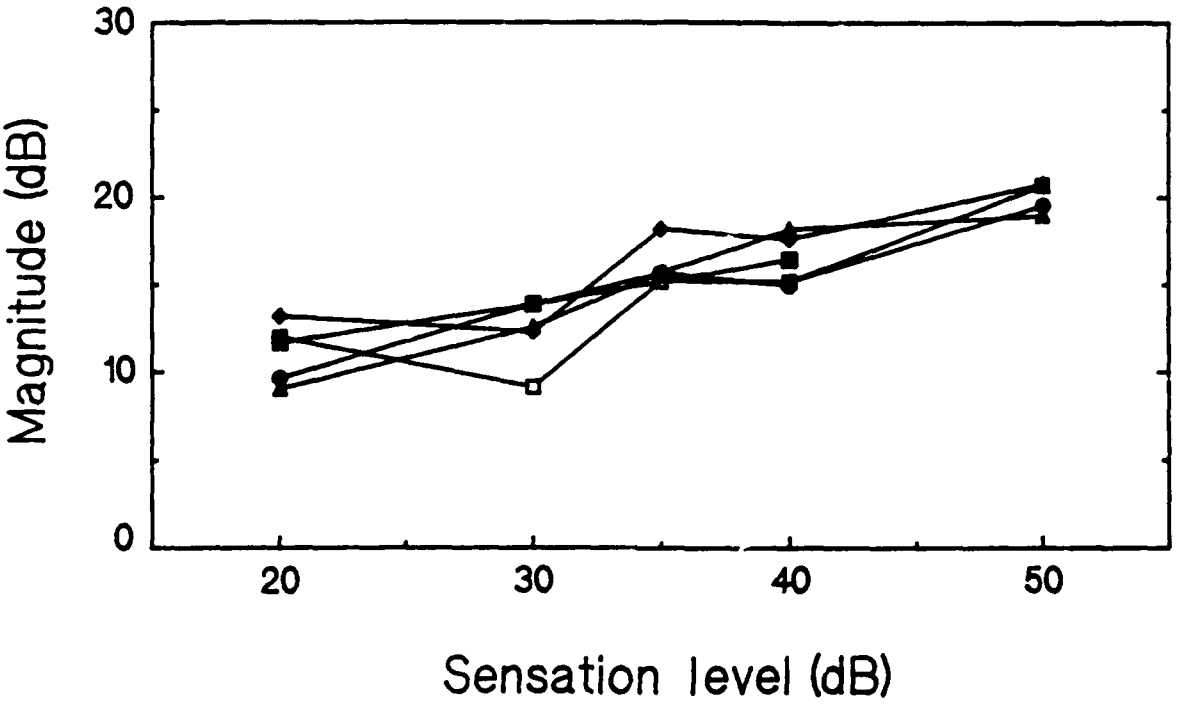

Figure 7. Mean magnitures of MRL respones for all subjects and all frequencies.

Filled circles: 250 Hz Open squares: 500 Hz
Filled diamonds: 1000 Hz Filled triangles: 2000 Hz
Filled squares: 4000 Hz

Discussion

Although the pilot data taken from one subject indicated that the averaged ABR responses to 2000 stimulus repetitions would be an adequate number upon which to base an estimate of the latency of the Wave V component, this did not prove to be the case in the main experiment. The variability both within and across subjects was unacceptably high. The latency changes produced by the full range of stimulus intensity often were exceeded by the standard deviation at any given intensity (Table 1).

Table 2.

MLR magnitudes and standard deviations. Means for all subjects. Values in all columns are in decibels.

Sensation level	Magnitude	Standard deviation
	0.25 kHz	
20	9.64	7.5
30	13.87	7.7
35	15.67	8.2
40	14.98	5.3
50	19.57	5.5
	0.50 kHz	
20	11.96	6.5
30	9.13	10.7
35	15.18	6.3
40	16.19	8.4
50	20.72	5.6
	1.00 kHz	
20	13.18	3.3
30	12.27	8.1
35	18.17	4.8
40	17.62	5.6
50	20.80	4.5
	2.00 kHz	
20	9.00	5.6
30	12.53	4.3
35	15.62	6.7
40	18.15	3.4
50	18.94	5.4
	4.00 kHz	
20	11.66	5.2
30	13.88	4.6
40	16.47	4.4

Most of the published reports regarding the magnitude of the 40-Hz component of the MLR as a function of stimulus level state that it is a good indicator of threshold. The variability of the measurements is rarely included in these reports, so that no meaningful comparisons can be made between them and the results of the present experiment in which the variability was considered unacceptably high. As in the case of the ABR results, the range of the dependent variable is small compared with the standard deviation at any given level (Table 2). Lenarz et al. (1986), however, do report the standard deviations for their measurements. For stimulus conditions similar to those of the present experiment, their variability appears to be comparable in magnitude. They attribute this large intrasubject and intersubject variability to contamination by myogenic potentials and to changes in the subject's state of vigilance. The variability of their data does decrease for near threshold levels, which they interpret to be the result of a decrease in myogenic potentials generated by cranial musculature. These potentials often contaminate middle latency responses, even when the subject appears to be in a relaxed state (Streletz et al., 1977). Since the present data were all collected at suprathreshold levels, the possibility of myogenic contamination cannot be ruled out.

Conclusions

When evoked by the proper stimulus, Wave V of the ABR can produce frequency-specific information. It must be averaged over a large number of repetitions before it can be considered a reliable indicator of effective stimulus level, however, making it an unsuitable measure for field work in which time is limited. Some reduction in variability and in data collection time might be achieved through the use of one of the automated statistical procedures mentioned earlier. However, the length of time required for such a procedure is determined in part by the signal-to-noise ratio, which could not be known in advance.

The MLR also is unsuitable for use as a rapid measure of effective stimulus level due to its large variability. This variability might be reduced by the use of a data-collection protocol which provides for the maintenance of the subject's attention within narrow limits. It is not clear, however, whether the possible contribution of myogenic potentials to the variability could be reduced to an acceptable amount at suprathreshold stimulus levels.

For the conditions examined in the present experiment, neither measure provides a reliable estimate of the effective stimulus level.

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